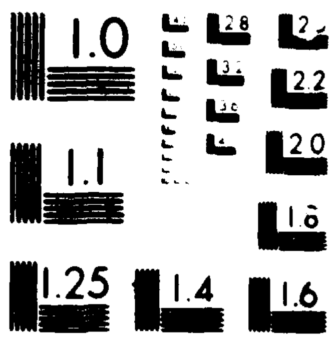
AD-A175 859 PULSE WAVE DELAY FOR +GZ TOLERANCE ASSESSMENT(U) NAVAL AIR DEVELOPMENT CENTER WARMINSTER PA AIRCRAFT AND CREW SYSTEMS TECHNOLOGY DIRECTORATE L HREBIEN APR 86 1/1

UNCLASSIFIED NADC-86140-60 F/G 6/19 NL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REPORT NO. NADC-86140-60

PULSE WAVE DELAY FOR $+G_z$ TOLERANCE ASSESSMENT

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INTERIM REPORT
Program Element No. 62758N

Prepared for
OFFICE OF NAVAL TECHNOLOGY
Department of the Navy
Washington, DC 20361

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REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION: Unclassified	1b RESTRICTIVE MARKINGS: N/A
2a SECURITY CLASSIFICATION AUTHORITY: N/A	3 DISTRIBUTION/AVAILABILITY OF REPORT: See Reverse Side
2b DECLASSIFICATION/DOWNGRADING SCHEDULE: N/A	
4 PERFORMING ORGANIZATION REPORT NUMBER(S): NADC-86140-60	5 MONITORING ORGANIZATION REPORT NUMBER(S): N/A
6a NAME OF PERFORMING ORGANIZATION: Naval Air Development Center; 6b OFFICE SYMBOL (If applicable): 60B1	7a NAME OF MONITORING ORGANIZATION: N/A
6c ADDRESS (City, State, and ZIP Code): Warminster, PA 18974-5000	7b ADDRESS (City, State, and ZIP Code): N/A
8a NAME OF FUNDING/SPONSORING ORGANIZATION: Office of Naval Technology; 8b OFFICE SYMBOL (If applicable): ONT 223	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: N/A
8c ADDRESS (City, State, and ZIP Code): Washington, DC 20361	10 SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO 62758 N; PROJECT NO N/A; TASK NO N/A; WORK UNIT ACCESSION NO N/A

11 TITLE (Include Security Classification)
Pulse Wave Delay for +Gz Tolerance Assessment

12 PERSONAL AUTHOR(S)
Leonid Hrebien, Ph.D.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Interim	FROM N/A TO N/A	April 1986	8

16 SUPPLEMENTARY NOTATION
N/A

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Pulse Waves; Doppler Flow; Acceleration Tolerance

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

We have found that pulse wave delay increases linearly with +Gz experienced by conscious subjects and that G-tolerance limits as measured using conventional light bars occur repeatedly at the same pulse wave delays or delta delay. When protective modalities such as anti-G suits or supinating seats are used, the delta delays increase at a slower rate as a function of +Gz. G-tolerance thresholds occur at higher +Gz levels with protection but the delta pulse wave delays reach the same value for all tolerance levels.

This parameter can be used to warn expert systems of the approach of GLOC during actual flight and/or provides an objective measure of G-protection provided by new or modified anti-G equipment. Therefore, this tool can be used in the research setting to evaluate the efficacy of G-protective equipment in an objective manner.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION: Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL: Leonid Hrebien, Ph.D.	22b TELEPHONE (Include Area Code): (215) 441-1490; 22c OFFICE SYMBOL: 60B1

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INTRODUCTION:

Current inventory and future generation high performance fighter and attack aircraft pose a significant and documented risk of G-induced Loss-of-Consciousness (GLOC). Improved performance characteristics such as high-G limits, higher G-onset rates, fly-by-wire with G-limiters and overall increased power and maneuverability contribute to this risk. In aircraft with these enhanced capabilities, GLOC can occur suddenly without the usual visual symptoms and produce 15 to 30 seconds of uncontrolled flight and possible loss of life and aircraft.

A possible solution to this problem is to develop expert systems to monitor consciousness of high performance aircrews and to automatically pilot the aircraft to safe controlled flight until the pilot is able to recover and take over control. These systems must be noninvasive and unobtrusive to the aircrew and provide physiologic and performance data to the system's decision algorythm. One such parameter is the change in the pulse wave delay or the difference between the EKG-R wave and the resultant pulse measured at head level (1)(2). We have found that pulse wave delay increases linearly with +Gz experienced by conscious subjects and that G-tolerance limits as measured using conventional light bars occur repeatedly at the same pulse wave delays or delta delay. When protective modalities such as anti-G suits or supinating seats are used, the delta delays increase at a slower rate as a function of +Gz. G-tolerance thresholds occur at higher +Gz levels with protection but the delta pulse wave delays reach the same value for all tolerance levels.

This parameter can be used to warn the expert system of the approach of GLOC during actual flight and/or provides an objective measure of G-protection provided by new or modified anti-G equipment. Therefore, this tool can be used in the research setting to evaluate the efficacy of G-protective equipment in an objective manner.

Figures 1, 2 and 3 show various transduction techniques for measuring pulse wave delay times. Figure 1 shows a two channel strip chart recording of a subject's EKG and ultrasonic doppler flowmeter signal from the superficial temporal artery just above the eye. The pulse wave delay is the time between the R wave in the EKG and the peak of the doppler flowmeter signal which represents blood velocity in the temporal artery. Figure 2 shows the EKG and infrared reflectance plethysmograph signal taken from the skin on the subject's forehead. Here the pulse wave delay is measured from the R wave to the peak of the plethysmograph signal. Figure 3 shows the EKG and rheoencephalogram (REG) of the head. Again, the pulse wave delay is measured from the R-wave to the peak of the REG. In each case the pulse wave delay measurement gives the delay time between the R wave of the EKG and the pulse measured at the head level. All three methods give the same pulse wave delay measure at 1 Gz and it is our belief that the optical plethysmogram and the rheoencephalogram will give similar increases in pulse wave delay times under +Gz as that measured using the ultrasonic doppler flowmeter.

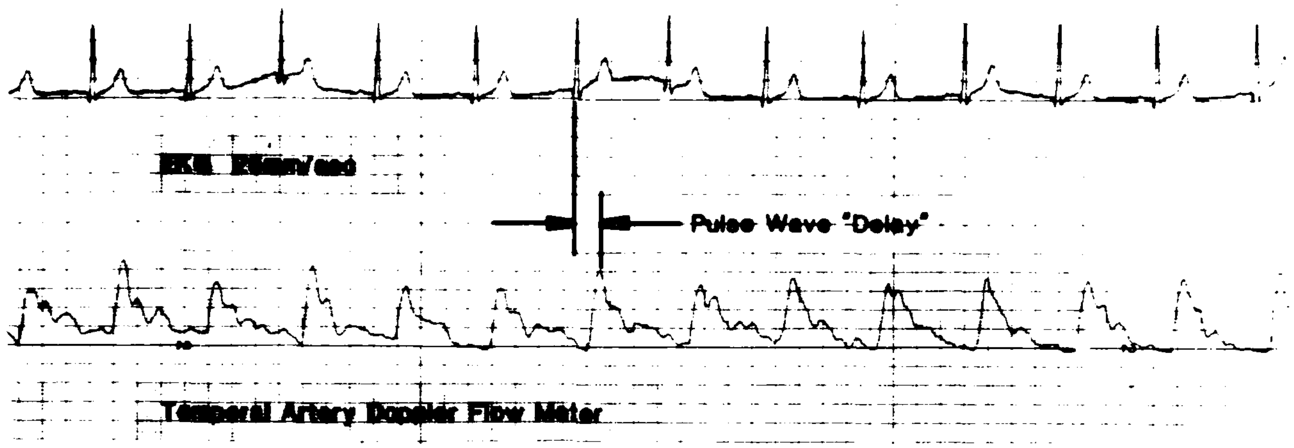

FIGURE 1 - EKG / Doppler Delay

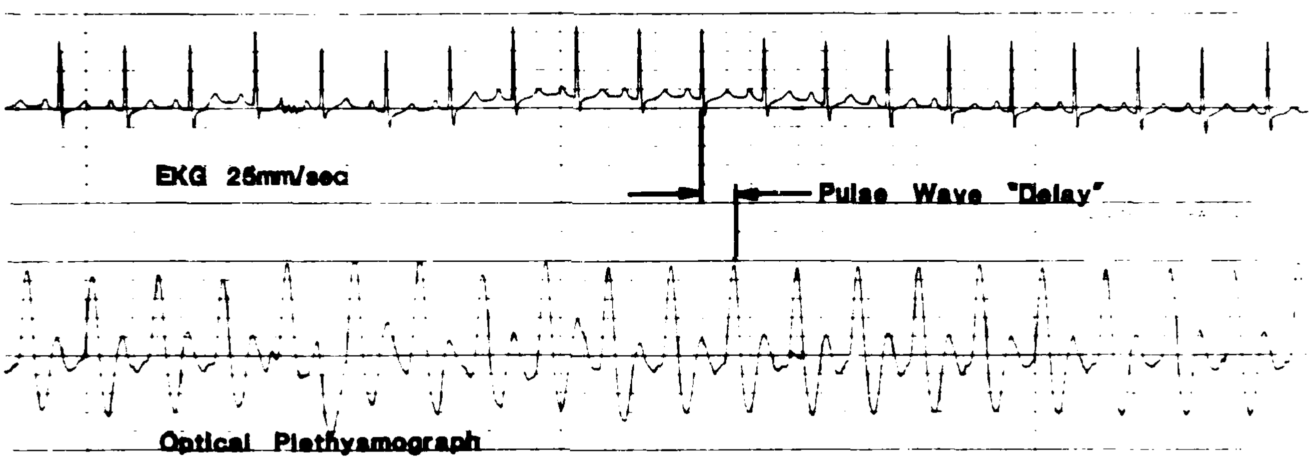

FIGURE 2 - EKG / Plethysmograph Delay

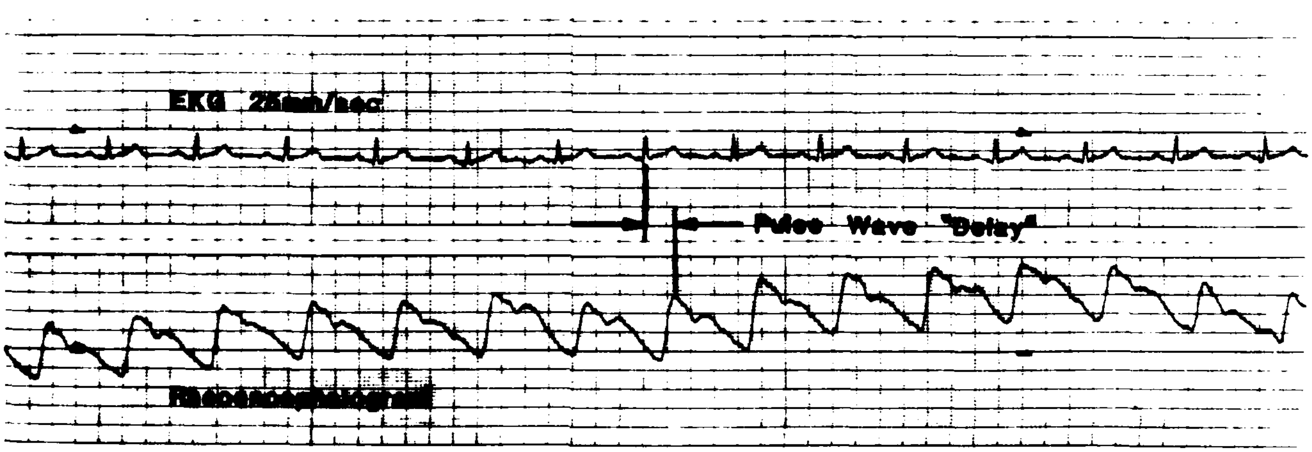

FIGURE 3 - EKG / Rheoencephalogram Delay

METHODS:

Eight human volunteers were exposed to increasing acceleration (+Gz) plateaus on the NAVAIRDEVCEN human centrifuge. Physiologic measures included two channels of EKG and a directional ultrasonic doppler flowmeter with a miniature 8.2MHz transducer located over the frontal branch of the superficial temporal artery. The subjects were evaluated under four different conditions of protection during the exposure to the acceleration plateaus: (a) seated upright, (b) seated upright with an anti-G suit, (c) supinated, (d) supinated with an anti-G suit. The G-tolerance of a subject was determined by using the NAVAIRDEVCEN lightbar. The lightbar provides a measure of peripheral vision loss. The endpoint in a run was defined as that point when vision collapsed to a 60 degree cone.

RESULTS:

The major metric in the analysis of the doppler pulse wave delay time is not the delay itself, but rather the change in the delay from the baseline delay found at 1G. This "Delta Delay" increases with increasing levels of acceleration as demonstrated in Figure 4. However, protective measures (e.g., AGS, Supination) reduce the amount of change for a given peak Gz. It is also evident that increasing protective measures produce a correspondingly greater reduction in the Delta Delay time, or delay times increased to a lesser degree with increasing protection for the same level. This is shown by calculating the slope Delta Delay/G. The slope of this line decreases for increasing levels of protection as shown in Figure 5. Also, prediction of G-tolerance based on a limit of Delta Delay for each subject correlates well with the G-tolerance given by the lightbar. G-tolerance endpoints predicted using Delta Delay and Delta Delay/G slope. are compared to conventionally measured lightbar endpoints in Figure 6.

CONCLUSION:

This technique should provide an objective, unobtrusive measure of +Gz protection for even subtle differences between G protective measures. The slope of Delta Delay/G could be determined using only fairly low levels of Gz, thereby allowing evaluation of G protective measures without the need to expose the subject to unneccessary stress or to rely on subjective performance tasks (e.g. lightbar tracking) to measure tolerance levels.

Ultimately, with the use of easily applied sensors such as capacitive EKG electrodes and infrared plethysmograph sensors which require no electrical contact with the pilot's skin and which could be integrated into a pilot's flight ensemble, this parameter could be available for in-cockpit monitoring.

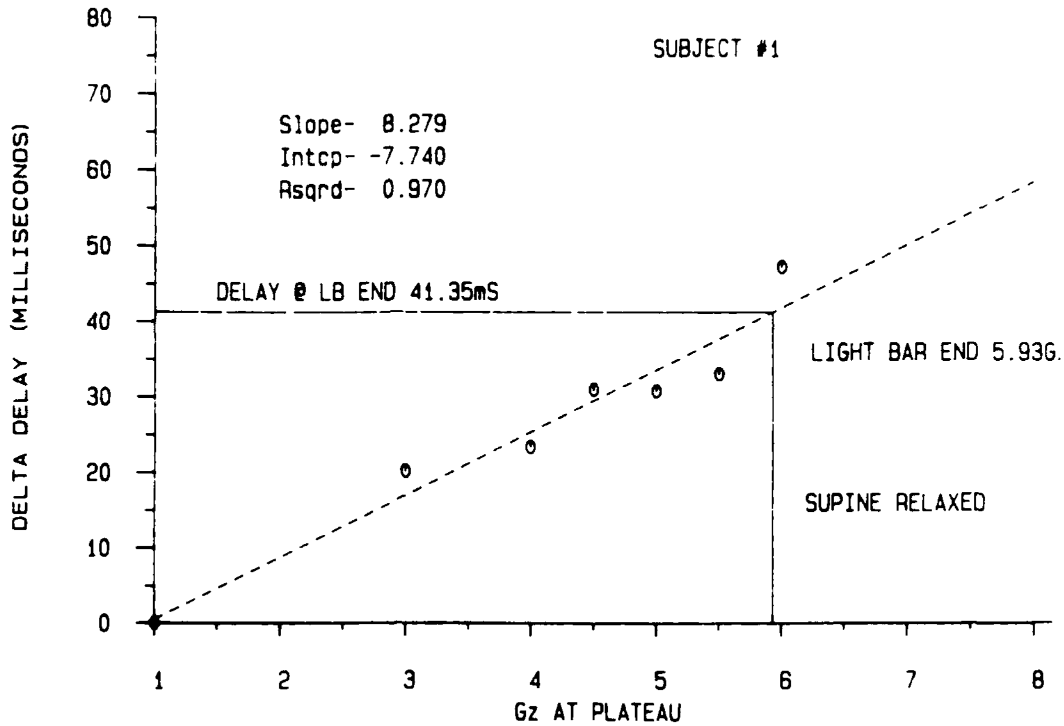

FIGURE 4 - Delta Delay as a Function of Gz Plateau Level

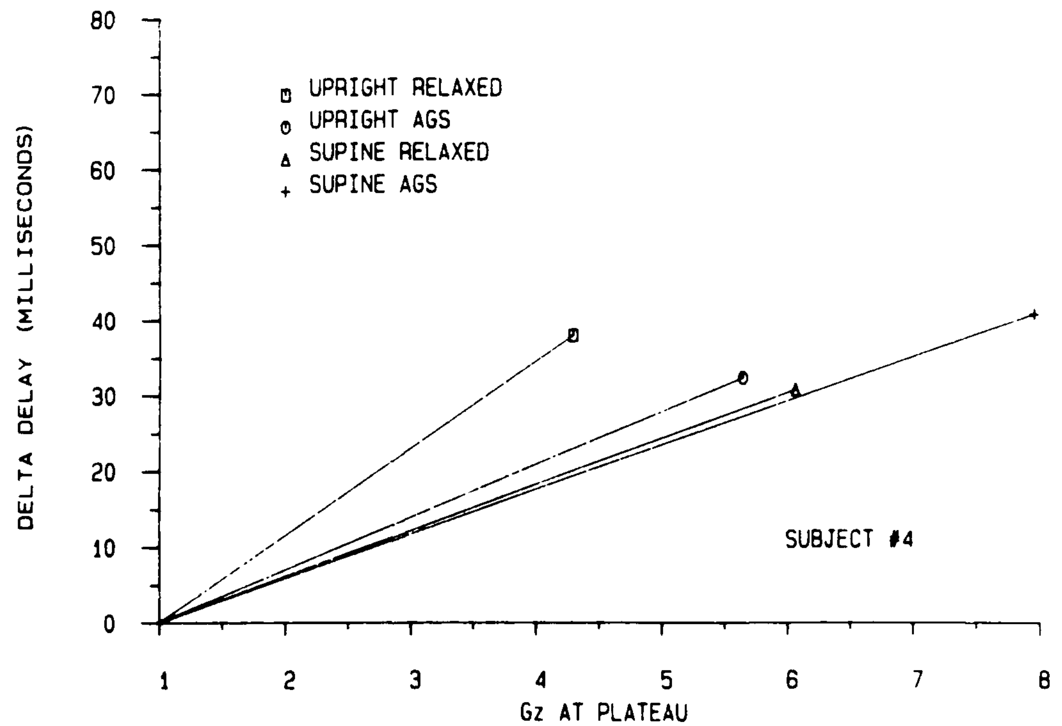

FIGURE 5 - Delta Delay as a Function of Gz with Light-Bar End Points

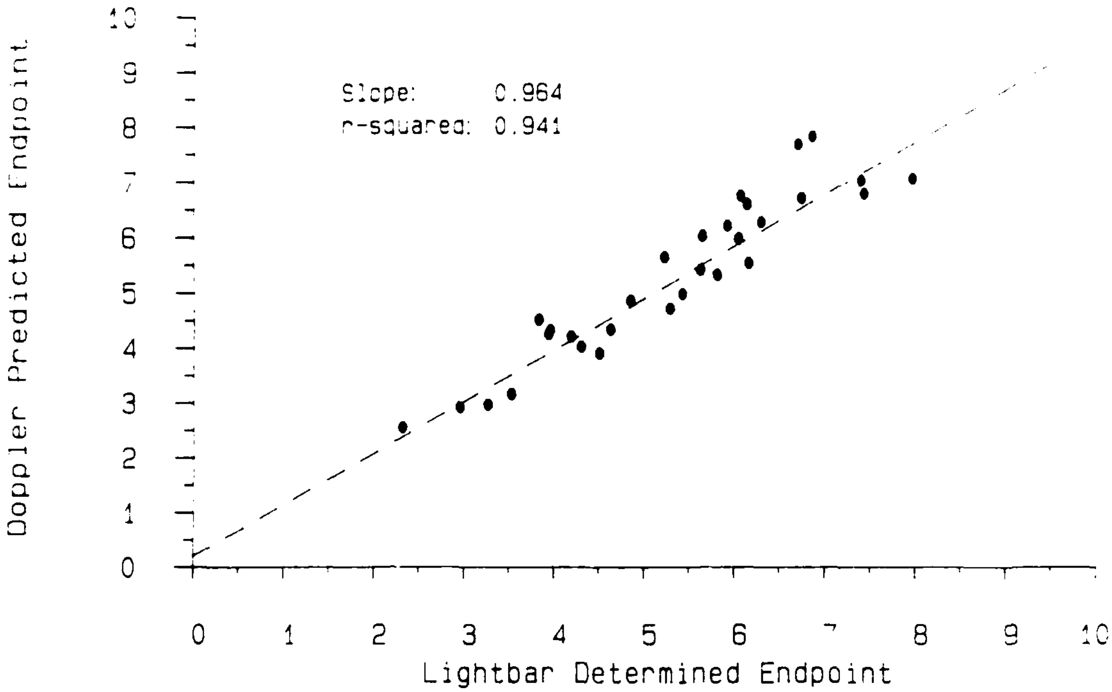

FIGURE 6 - Light-Bar End Points Compared to Delta Delay Predicted End Points (for 8 subjects and 4 conditions of protection)

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